WINGS OF THE CXO PSF

Calibration Review Presentation: 30 Oct 2001

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HRMA PSF WINGS

On-axis PSF

- PSF core ($\lesssim$90% encircled energy)
  - low frequency mirror figure errors; misalignments
- PSF wings
  - scattering from mirror microroughness (high frequency errors)
  - low level (especially at low energies); requires bright source to see wings above background, leading to pile-up for ACIS detectors.
  - expected to be steep at low energy, flatter at high energies.

Calibration Aims

- Qualitative
  - PSF shape – "is my source extended?"
- Quantitative
  - PSF as "background"; something to be subtracted accurately, *e.g.*, extracting an X-ray dust scattering halo.
  - need shape, absolute normalization, as function of E.

XRCF Wing Scans

Normalized surface brightness, pinhole p, shell s:

$$\mathcal{S}_{s,p}(\theta) \simeq \frac{f_{qc} w_p}{\Omega_{s,p}} \frac{\mathcal{R}_{s,p}(\theta)}{\mathcal{R}_{s,35mm}(0)} \ (\text{cts s}^{-1} \text{ sterad}^{-1}/\text{source cts s}^{-1})$$

where

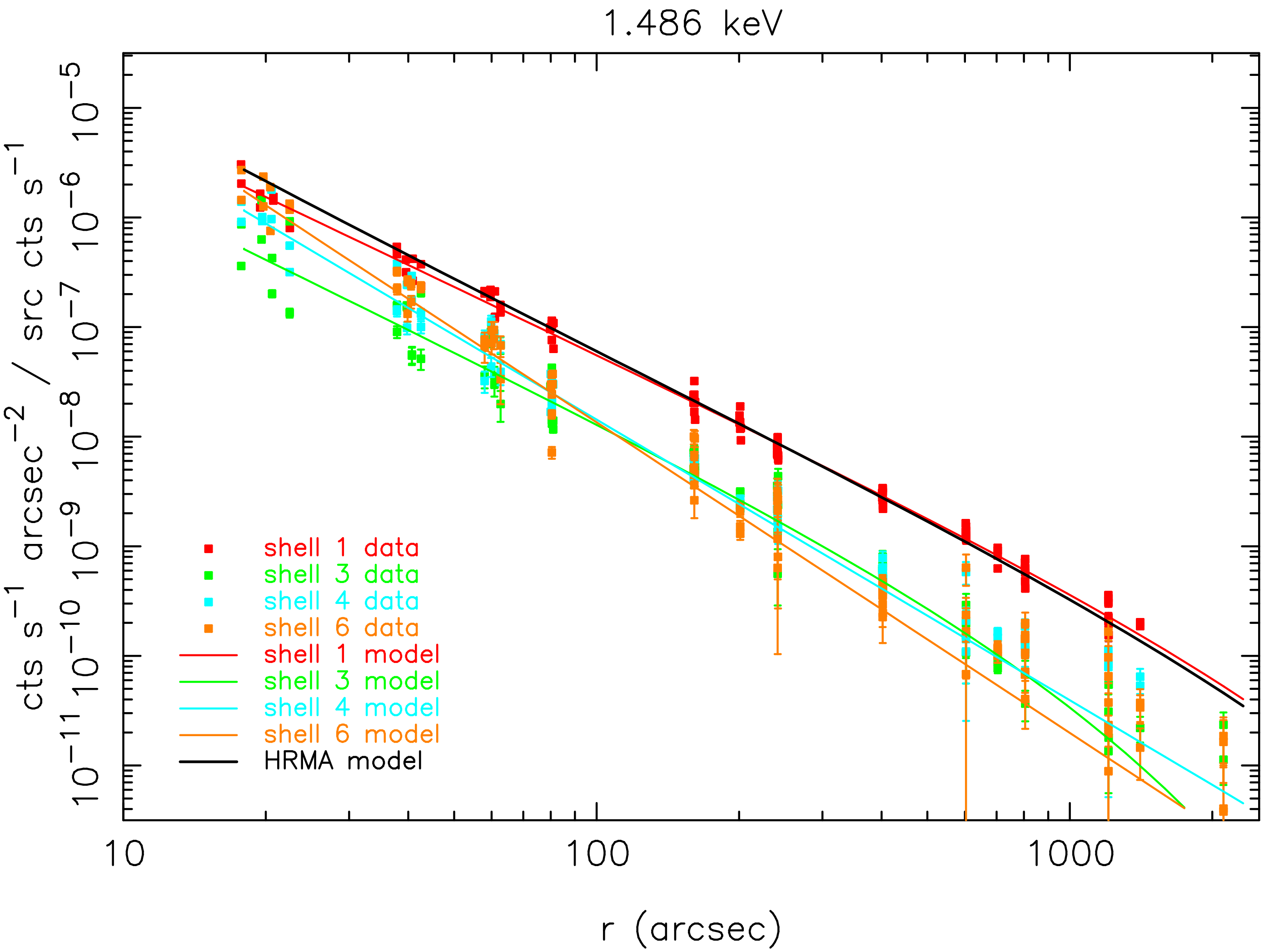
$\mathcal{R}_{s,p}(\theta)$	$=$ count rate, pinhole p, (cts s^{-1})
$\mathcal{R}_{s,35mm}(0)$	$=$ count rate, on-axis 35mm pinhole, full shell, (cts s^{-1})
$\Omega_{s,p}$	$= \pi\,(d_p/4F_{fc})^2 =$ solid angle, pinhole p, (sterad)
w_p	$=$ pinhole correction factor (slope of wing profile across pinhole)
f_{qc}	$\sim$2, quadrant shutter correction factor; scattering is mainly in-plane: off-axis pinhole gets $\sim$1/2 of scattered flux; on-axis pinhole gets $\sim$1/4 specular flux.

Procedure:

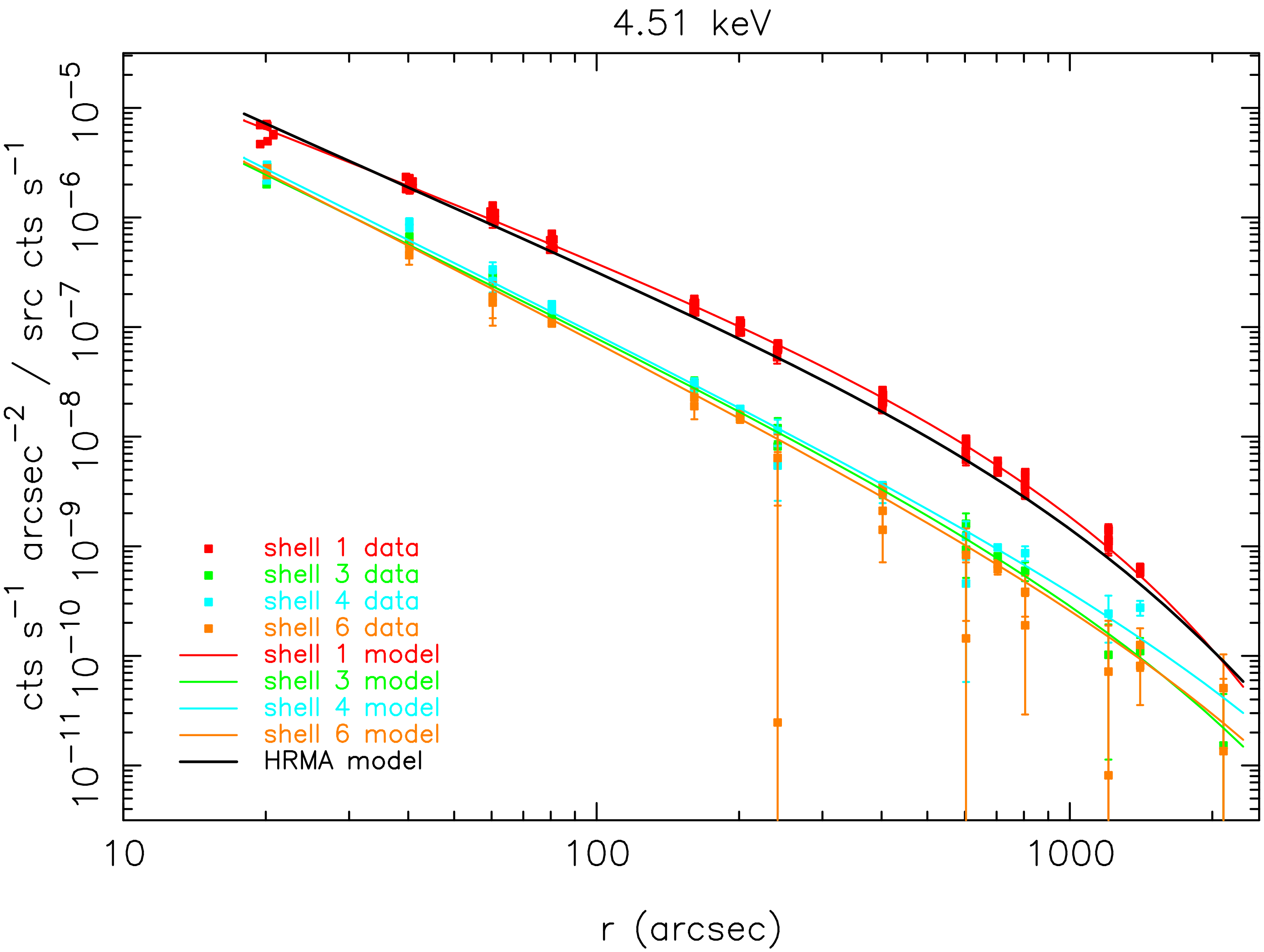
- Remove pinholes vignetted by quadrant shutters.
- Fit exponentially truncated powerlaw to $\mathcal{R}_{s,p}(\theta)$ to get $\mathcal{R}_s(\theta)$, model profile for shell s. $[\mathcal{R}_s(\theta) = a\theta^\alpha \exp(-\theta/\theta_0)]$
- Combine shells, weighted by on-axis effective area for shell as fraction of HRMA on-axis effective area.

$$\mathcal{S}_{HRMA}(\theta) = \frac{\sum_s A_s \mathcal{S}_s(\theta)}{\sum_s A_s}$$

HRMA PSF – Wings (XRCF)



HRMA PSF – Wings (XRCF)



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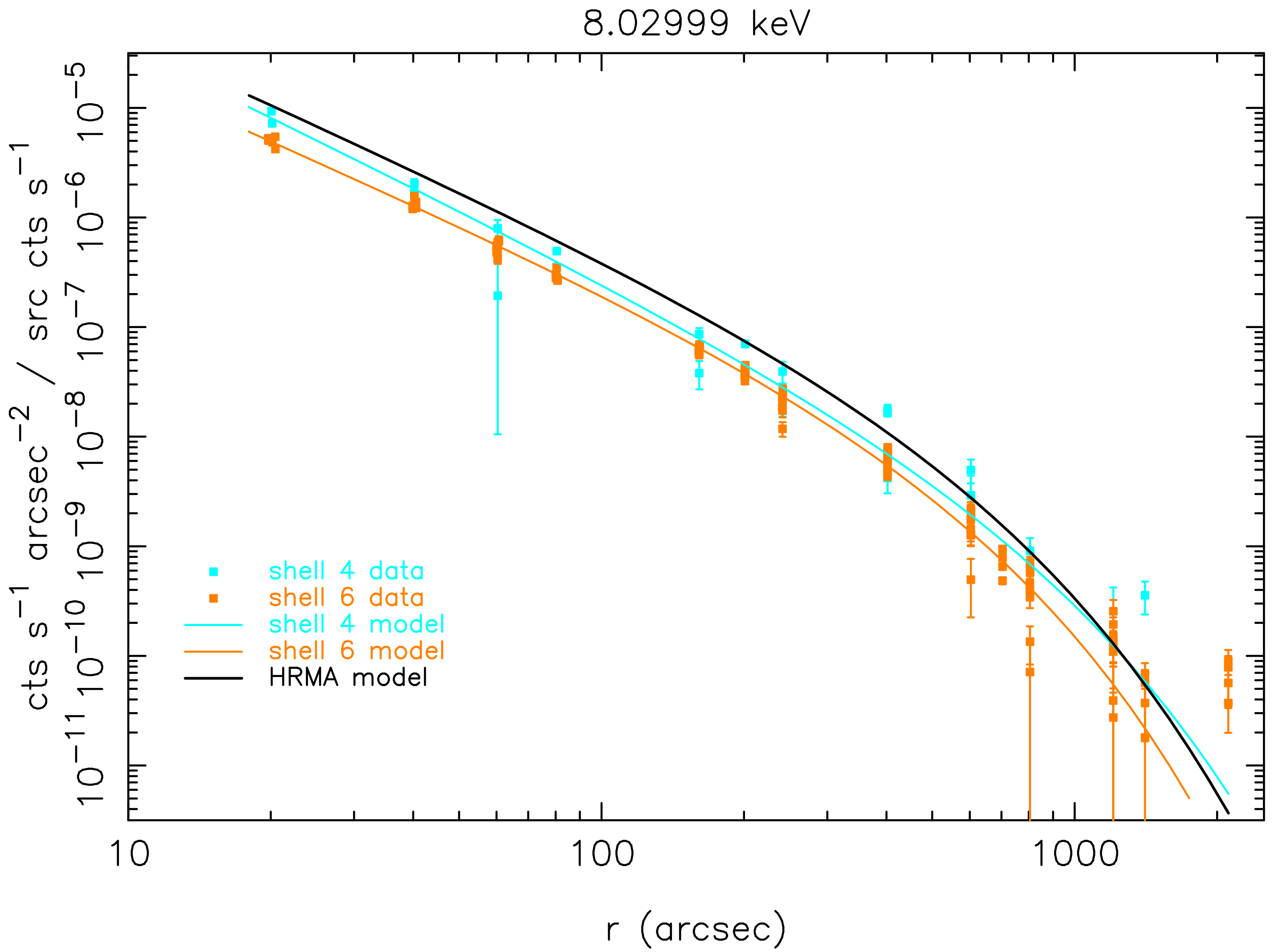

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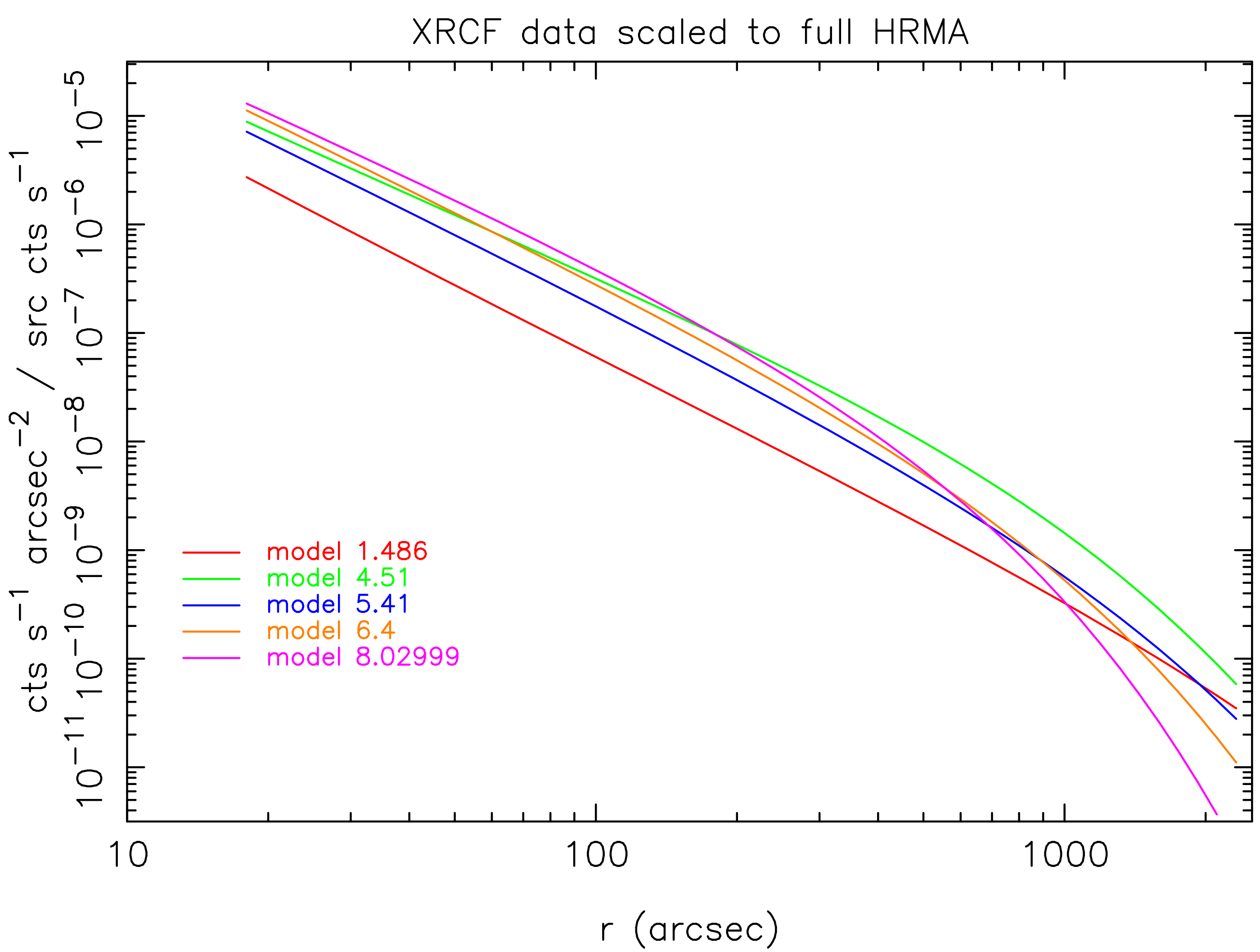
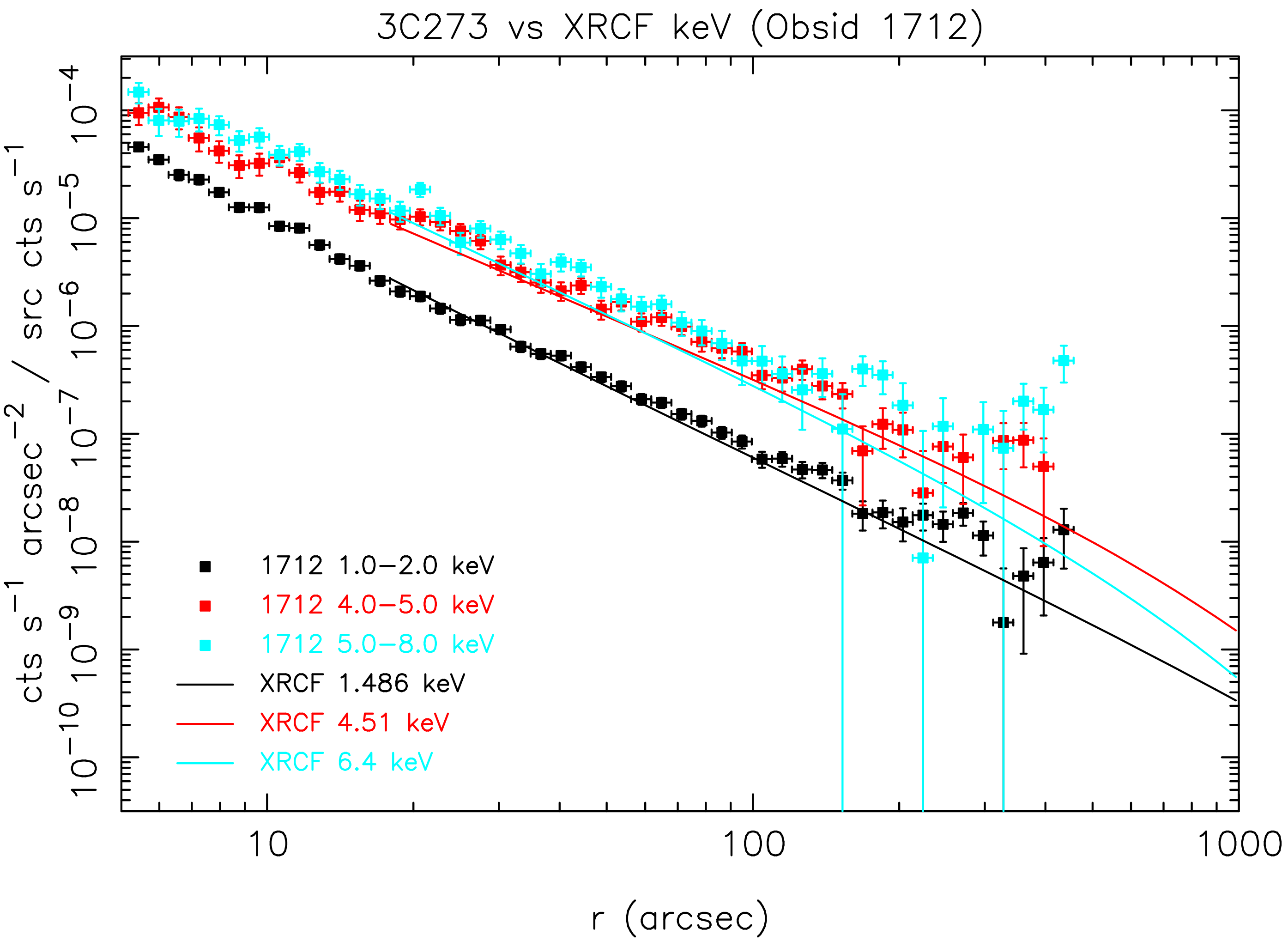
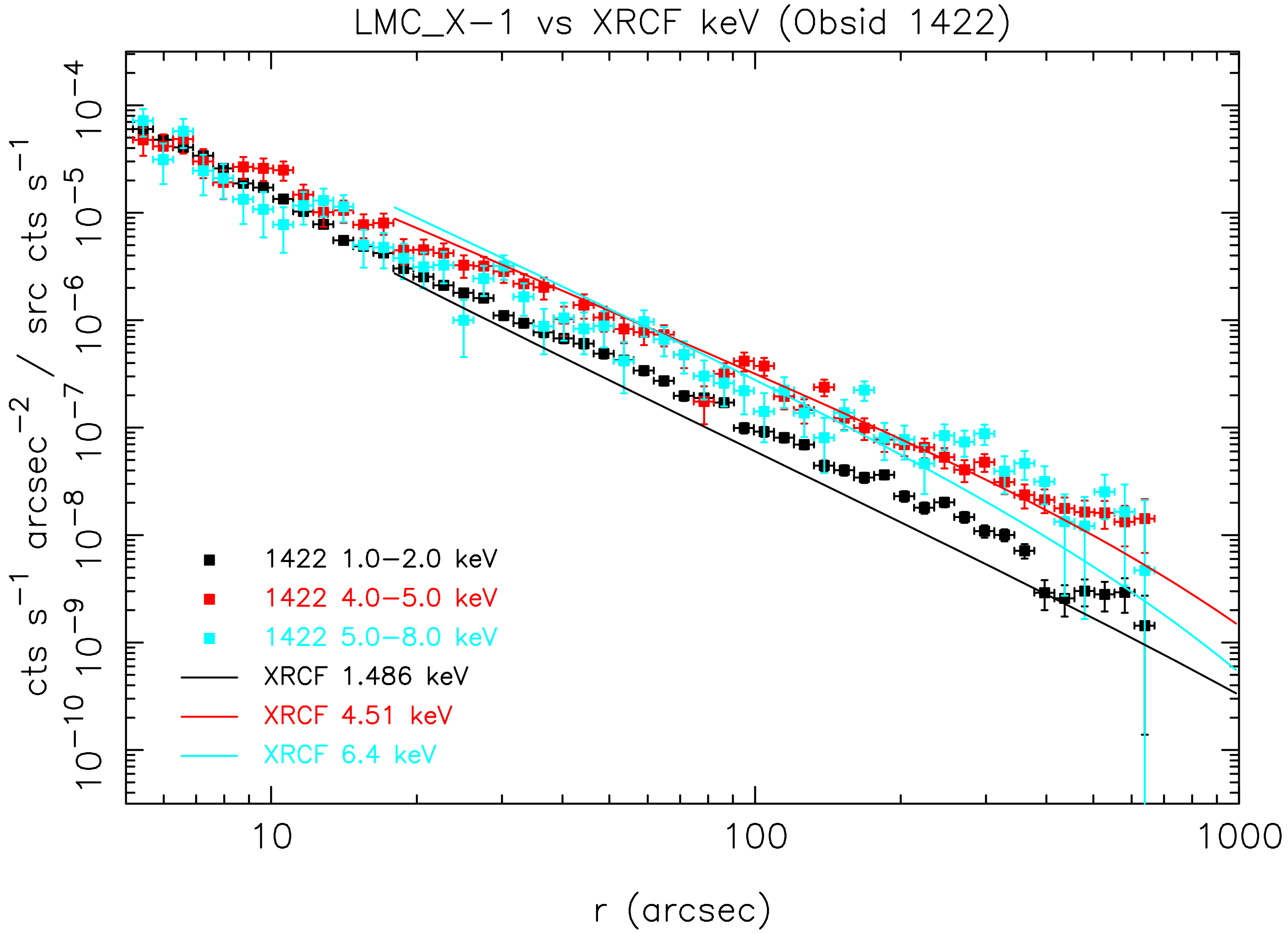


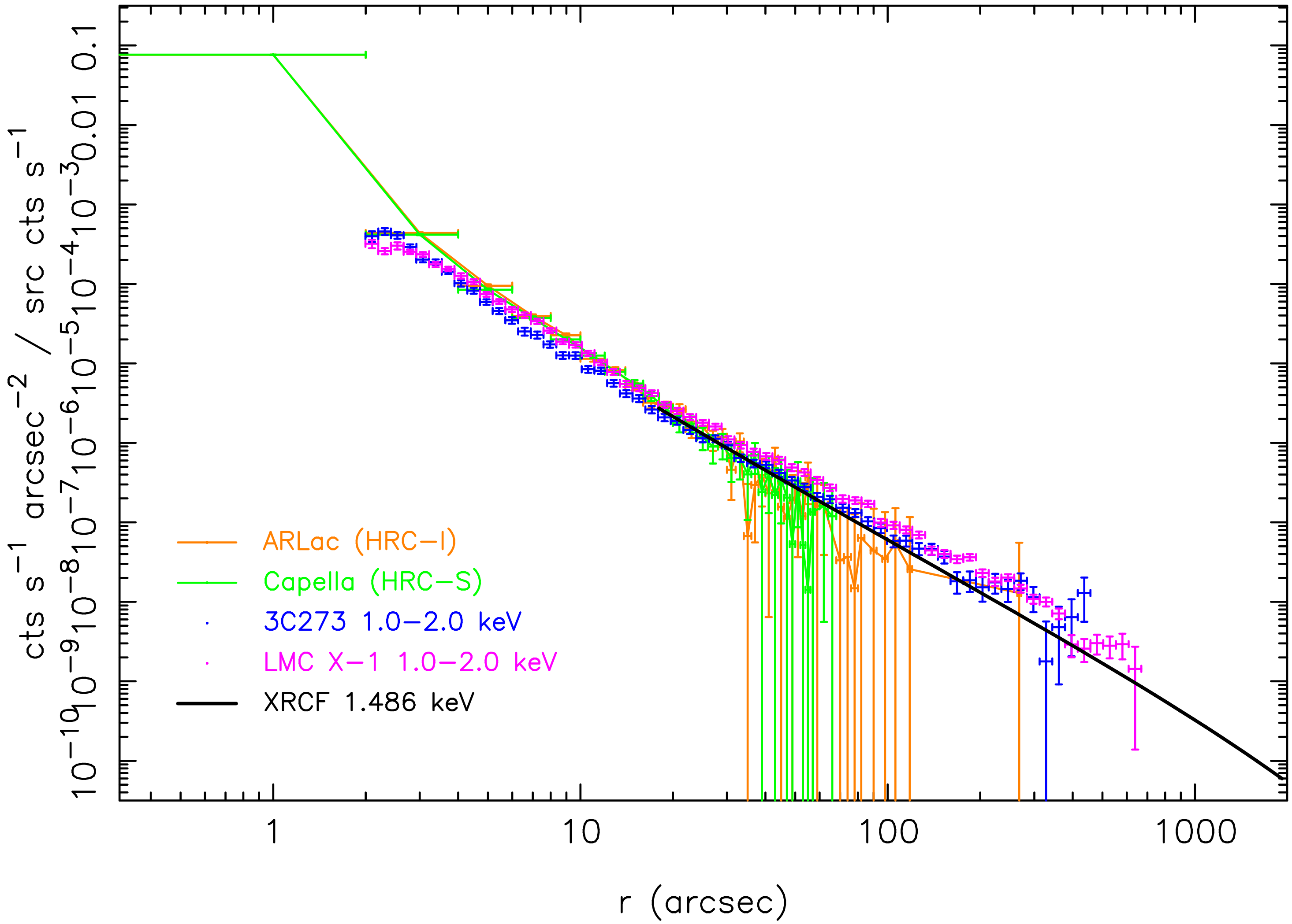
HRMA PSF – Wings



HRMA PSF – Wings



HRMA PSF – Wings – Low Energy



On-Orbit Data

- obsid 01712: 3C273 on ACIS-S3
  - failed grating insertion
  - $\sim$30 ks total, GTI $\sim$22 ks
  - $N_{HI} = 1.69 \times 10^{20}$ cm^2 (Lockman & Savage 1995, *ApJS*, **97**, 1)
- obsid 01422: LMC X-1 on ACIS-I
  - $\sim$4 ks total, GTI $\sim$4 ks
  - $N_H \simeq 10^{22}$ cm^2; 2.9% dust X-ray halo reported (Predehl & Schmitt 1995, *A&A*, **293**, 889)
  - complex field, *e.g.* SNR 0540-6944 within a few arcmin (Williams *et al.* 2000, *ApJL*, **536**, L27)
- obsid 62426: Capella on HRC-S
  - failed grating insertion
  - $\sim$25 ks total, GTI $\sim$11 ks
  - $N_{HI} = 1.8(+0.3, -0.1) \times 10^{18}$ cm^2 (Linsky *et al.* 1993, *ApJ*, **402**, 694)
- obsid 01385: AR Lac on HRC-I
  - $\sim$19 ks total, GTI $\sim$19 ks
  - $N_{HI} = (5.9 \pm 2.5) \times 10^{18}$ cm^2 (Rodonò *et al.* 1999, *A&A*, **346**, 811)

HRMA PSF – Wings

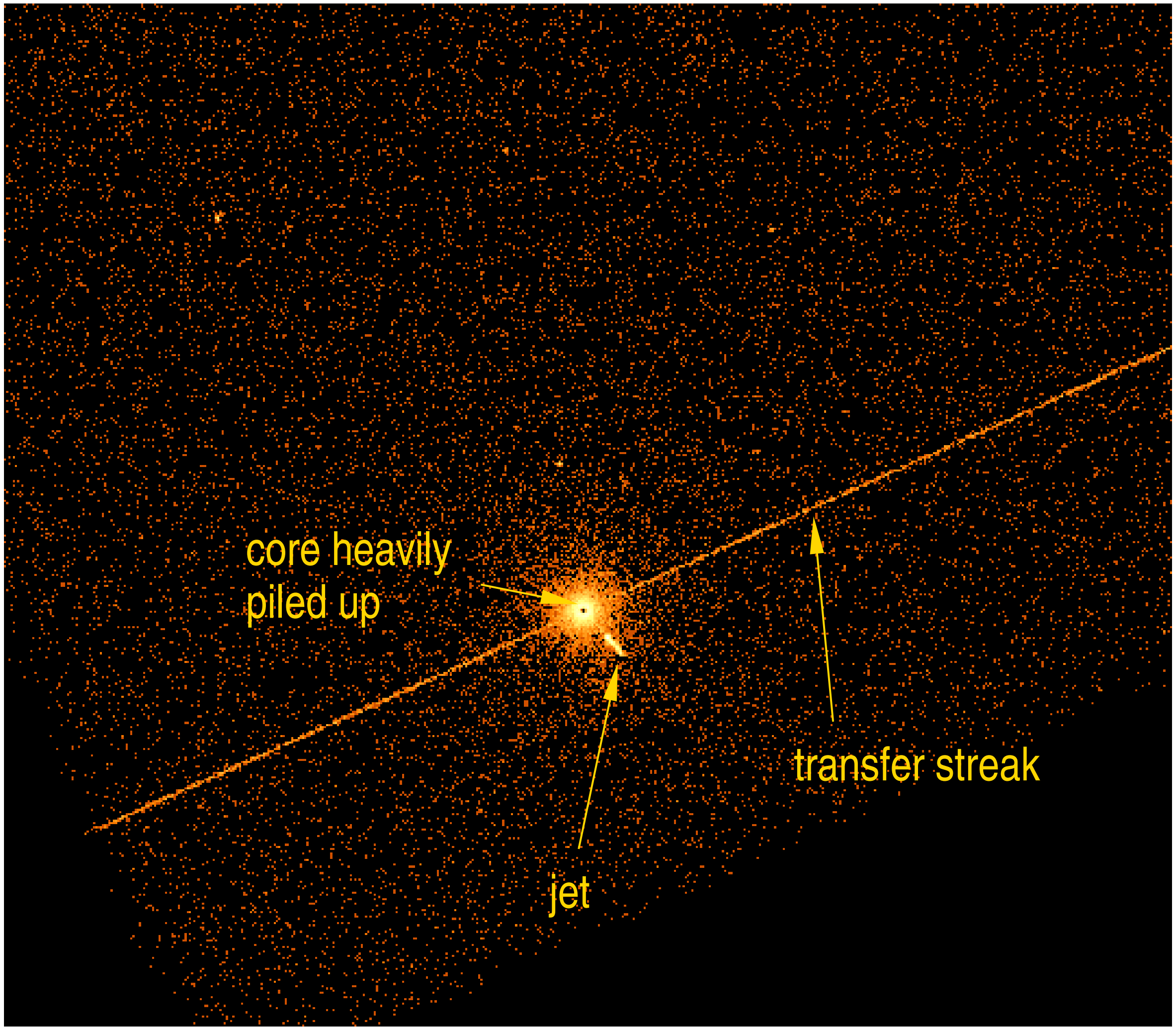


Figure 1: 3C273 on S3.

HRMA PSF – Wings

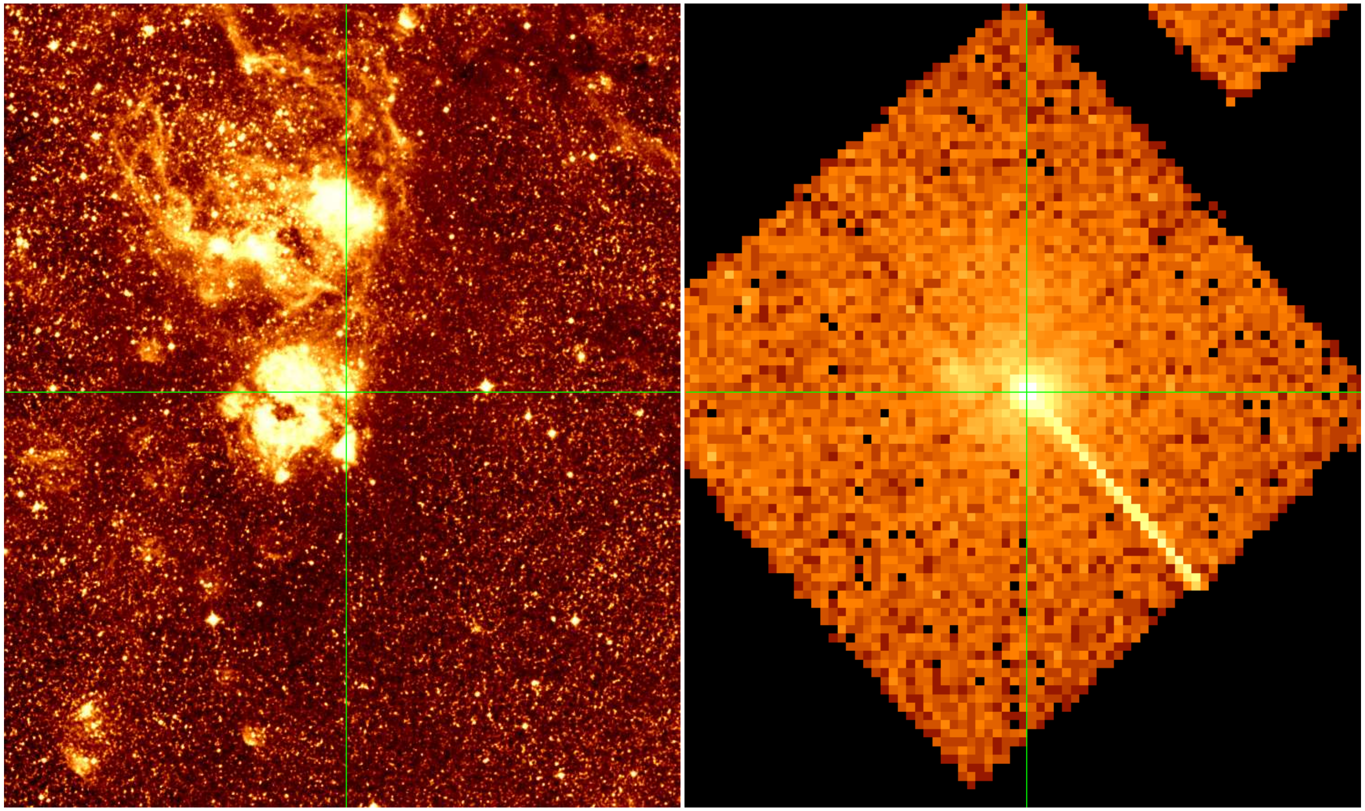


Figure 2: LMC X-1: Left: XDSS r. Right: Chandra ACIS-I.

HRMA PSF Wings - Issues

Issues

- normalization of wings
- better statistics at higher energies
- core-wing transition (as a function of energy)
  - core: $\lesssim$few arcsec
  - wings: $\gtrsim$10 arcsec
- XRCF data
  - core: treatment of "missing shells"
  - wings: systematics (quad shutter correction; tilt of HRMA)

Plans

- wings as function of energy – need more data
  - deep exposure on ACIS-I of bright, clean source (*e.g.*, HR1099, 3C273, Capella)
- far core/near wings
  - search for on-axis intermediate strength sources; less pile-up gets us closer to the core.

PSF Wings - Extraction Procedure

For each energy band ΔE:

- Construct instrument-only QE map (dithered instrument map, HRMA area set to 1).
- Analysis makes use of **`funcnts`**:
  - construct annulus centered on source (approximately logarithmic spacing).
  - excise sources which could contaminate wings (*e.g.* jet in 3C273, SNR 0540-6944 in LMC X-1 region)
  - excise region around ACIS transfer smear from core of source
  - use **`funcnts`** to extract counts in each annulus for binned image; evaluate surface brightness, $\mathcal{S}$.
  - use **`funcnts`** to extract mean QE, $\langle QE \rangle(\theta)$, for each annulus for corresponding instrument-only QE map.
  - divide $\mathcal{S}$ by QE for each annulus, to get corrected $\mathcal{S}_{corr} = \mathcal{S}(\theta)/\langle QE \rangle(\theta)$.
  - fit $\mathcal{S}_{corr}$ with a model of the form $\mathcal{S}_{corr}(\theta) = a\theta^{\alpha} + b$; b is an estimate for the background. Because of heavy pile-up near the core, the fit was for $\theta \geq 10''$.
  - normalize the profile using the source count rate for the energy band to get a normalized profile: $\mathcal{S}_{corr,norm}(\theta) = \mathcal{S}_{corr}/\mathcal{R}_{source}$

PSF Wings - Extraction Procedure

Evaluation of the source rate:

- Extract the spectrum from a narrow strip centered on the bright transfer streak, avoiding heavily piled-up region near the core. Note: the RMF and ARF are evaluated for the location of the source, not the location of the streak.
- Fit the spectrum. Extract the count rate for energy band ΔE.
- Correct for the effective exposure time of the streak: exposure time / (length of streak in pixels $\times$ number of ACIS frames $\times$ pixel transfer time [4×10^{-5} sec/pixel]). The source count rate is multiplied by this factor. The rate is also divided by the QE at the source location (so that the profile and source rate have both been divided by $\langle QE \rangle$).

HRMA PSF Wings - Caveats

This is work in progress. Some caveats:

- Ground Calibration Data (XRCF)
  - Backing out ground calibration effects, *e.g.*
    - Illumination of the optics is different than on-orbit; this emphasizes the smoother middle portion of the optics $\Longrightarrow$ expect profiles to somewhat underestimate the wings.
    - Normalization of the data points: assumed an approximate correction for the effects of the quadrant shutters; assumed to be exactly a factor of 2, but could vary depending on off-axis distance and direction (scattering to smaller or larger angles from the optic surface).
  - Longer term: iterative refinement of scattering model for raytrace to improve agreement with models; this will allow the ground effects & systematics to be backed out more reliably.
- Sky data (ACIS)
  - Provides an upper limits on wings (there may be astrophysical effects (*e.g.*, dust scattering halos) which broaden the PSF; need "clean" lines of sight.
  - Systematics, *e.g.*:
    - Depression of inner regions by detector pile-up effects.
    - Background subtraction uncertainties; vignetted *vs.* unvignetted background.
    - Evaluation of source rate for absolute normalization.
    - Slope of wings across sampling annulus; adjust effective radius of annulus.

HRMA PSF Wings - More Caveats

More caveats:

- Sky data (HRC)
  - Figures based on an early analysis of the data; needs to be redone with smaller annular spacing in the near to mid wings.
  - Need to account for slope of wings across annuli; effective radius correction.
  - HRC count rates can be evaluated by direct summation; correction for difference between direct sum (HRC) and indirect transfer streak (ACIS) evaluation of source count rates.
- General
  - Normalization between ground and sky data may not be consistent yet.
  - Ground data may be systematically steeper than on-orbit profile; is this a ground calibration effect (uneven mirror illumination) or is it real?